

METHOD FOR FORMING A FLOW DIRECTOR ON
A HOT GAS PATH COMPONENT

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This application is related to commonly assigned U. S. Patent Application, R.S. Bunker et al., entitled "Component and Turbine Assembly with Film Cooling" and filed concurrently herewith, which is hereby incorporated by reference in its entirety.

BACKGROUND OF THE INVENTION

[0002] The invention relates generally to hot gas path components for turbine assemblies and, more particularly, to film cooling of hot gas path components and to secondary cooling between hot gas path components.

[0003] A variety of components in aircraft engines and stationary power systems are operated in extremely hot environments. These components are exposed to hot gases having temperatures up to 3400 degrees Fahrenheit, for aircraft applications, and up to about 2700 degrees Fahrenheit for stationary power generation applications. To cool the components exposed to the hot gases, these "hot gas path" components typically have both internal and film cooling. For example, a number of cooling holes may extend from a relatively cool surface of the component to a "hot" surface of the component. The hot surface is exposed to the hot gases and thus requires more thermal management than does the relatively cool surface of the component, which may itself be at a temperature of about 1000 to about 1800 degrees Fahrenheit. This technique is known as film cooling. The coolant typically is compressed air bled off the compressor, which is then bypassed around the engine's combustion zone and fed through the cooling holes to the hot surface. The coolant forms a protective "film" between the hot component surface and the hot gas flow, thereby helping protect the component from heating.

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[0004] Because bleeding the coolant off the compressor reduces the overall efficiency of the engine, it is desirable to improve cooling effectiveness for a given amount of coolant. A number of techniques have been employed to enhance the effectiveness of film cooling, including using "shaped" cooling holes. Film cooling is highest when the coolant flow hugs the hot surface. However, conventional film cooling techniques can be improved to further direct and maintain the coolant flow along the hot surface.

[0005] Accordingly, it would be desirable to provide film cooling for hot gas path components with improved cooling effectiveness. More particularly, it would be desirable to further direct and maintain the coolant flow along the hot surface of the gas path component, to enhance the protective "film" effectiveness.

SUMMARY

[0006] Briefly, in accordance with an embodiment of the present invention, a method for forming a flow director on a component is described. The method includes depositing at least one layer on the wall of the component. The deposition includes shaping the layer in accordance with a predetermined shape to form the flow director.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] These and other features, aspects, and advantages of the present invention will become better understood when the following detailed description is read with reference to the accompanying drawings in which like characters represent like parts throughout the drawings, wherein:

[0008] FIG. 1 shows an exemplary film-cooled airfoil with two exemplary rows of film-cooling holes;

[0009] FIG. 2 shows the airfoil of Figure 1 in cross-sectional view and depicts one of the exemplary film-cooling holes formed in the wall of the airfoil and an exemplary flow modifier formed on the hot surface of the wall;

[0010] FIG. 3 is an enlarged view of the exemplary film-cooling hole and exemplary flow modifier of Figure 2;

[0011] FIG. 4 is a top view of an exemplary flow modifier;

[0012] FIG. 5 is a top view of another exemplary flow modifier;

[0013] FIG. 6 is a top view of an exemplary arrangement of flow modifiers;

[0014] FIG. 7 is a top view of another exemplary arrangement of flow modifiers;

[0015] FIG. 8 shows an exemplary arrangement of film-cooling holes, flow modifiers and connectors for a hot gas path component;

[0016] FIG. 9 is a view of the flows modifiers and connectors of Figure 8 taken along the line 43;

[0017] FIG. 10 shows an exemplary flow modifier and pair of ridges formed on the hot surface of the component wall;

[0018] FIG. 11 is an enlarged view of the exemplary film-cooling hole and exemplary ridge of Figure 10, with the flow modifier omitted;

[0019] FIG. 12 depicts an exemplary arrangement of film-cooling hole exit sites and ridges;

[0020] FIG. 13 is a top view of another flow modifier embodiment;

[0021] FIG. 14 is a side view of the flow modifier of Figure 13;

[0022] FIG. 15 illustrates a turbine assembly embodiment of the invention;

[0023] FIG. 16 illustrates a method of forming a flow director, such as a flow modifier, connector or ridge, on a component;

[0024] FIG. 17 is a top view of an exemplary flow modifier positioned upstream of the exit site of the film-cooling hole;

[0025] FIG. 18 shows an exemplary arrangement of linear flow modifiers on sides of the components shown in FIG. 15; and

[0026] FIG. 19 shows an exemplary arrangement of curved flow modifiers on sides of the components shown in FIG. 15.

DETAILED DESCRIPTION

[0027] A component 10 with film cooling is described with respect to Figures 1-3. Exemplary film cooled components include hot gas path components in turbines, for example stationary vanes (nozzles), turbine blade (rotors), combustion liners, other combustion system components, transition pieces, and shrouds. The present invention is applicable to all hot gas path surfaces in a turbine engine. Figure 1 shows an airfoil 10 as an exemplary embodiment of the component 10. The airfoil 10 is shown in cross-section in Figure 2. The component 10 includes a wall 12 having a cold surface 21 and a hot surface 22. At least one film-cooling hole 14 extends through the wall 12 for flowing a coolant from the cold surface 21 to the hot surface 22. An exemplary film-cooling hole 14 is shown in an enlarged view in Figure 3. An exemplary coolant is air, for example compressed air. It should be noted that the terms "hot" and "cold" surfaces are relative. As used here, the hot surface 22 is the surface of the wall 12 exposed to hot gases, and the cold surface 21 is the surface from which the coolant flows. As indicated in Figure 3, the film-cooling hole is typically angled relative to hot and cold surfaces 22, 21. Beneficially, an angled film-cooling hole 14 provides a longer cooling length for a given wall thickness. However, for certain applications, straight film-cooling holes 14 may be employed. As shown in Figure 3, the film-cooling hole 14 defines an exit site 16 in the hot surface 22 of the wall 12. Coolant exits the film-cooling hole 14 through the exit site 16. The

component 10 further includes at least one flow modifier 30 formed on the hot surface 22 of the wall 12. The flow modifier 30 is adapted to direct the coolant flowing from the film-cooling hole 14 and out of the exit site 16 toward the hot surface 22 of the wall 12. As indicated in Figure 3, the flow modifier 30 extends outwards from the hot surface 22 of the wall 12 and conforms to the hot surface 22 of the wall 12.

[0028] According to a particular embodiment, the flow modifier 30 extends less than about 0.7 mm from the hot surface of the wall 12 and, more particularly, the flow modifier 30 extends a distance in a range of about 0.1 mm to about 0.25 mm, from the hot surface of wall 12. The desired thickness of the flow modifier 30 depends on a number of factors, including material, geometry, type of hot gas path component 10, position on the component 10, and application.

[0029] Beneficially, the flow modifier 30 enhances the film cooling provided by the film-cooling hole 14 by directing the coolant flowing from the film-cooling hole 14 and out of the exit site 16 toward the hot surface 22 of the wall 12. The coolant provides a protective barrier that reduces the contact between the hot gases and the wall 12. The component 10 of this embodiment has two related advantages over conventional film-cooled hot gas path components. First, the component 10 can be maintained at a lower temperature relative to a conventional film-cooled hot gas path component, for a given coolant throughput. Alternatively, the amount of coolant used can be reduced, while achieving the same amount of film cooling for the component 10 of this embodiment, relative to a conventional film-cooled component. Reducing the amount of coolant used increases the efficiency of a turbine engine because less coolant is bled from the compressor (not shown).

[0030] The number of film-cooling holes 14 formed in the component 10 depends on the amount of cooling needed. The amount of cooling required depends on the application, for example stationary power generation or aircraft engine applications, as well as on the position of the component 10 in the turbine engine, for example whether the component 10 is in stage 1 or stage 2 of the turbine engine. For heavily cooled parts, for example airfoils positioned immediately after the combustion

section (not shown), which see the hottest gases, on the order of 700 film-cooling holes 14 may be formed in the wall 12 of the airfoil 10. For components requiring less cooling, a few film-cooling holes 14 may suffice, and for intermediate levels of cooling, a few rows 32 of film-cooling holes 14 (corresponding to around sixty film-cooling holes 14) are used. Accordingly, the two rows 32 of film-cooling holes 14 shown in Figure 1 are purely illustrative, with respect to both the desired number and positions of the film-cooling holes 14.

[0031] Film-cooling holes 14 are formed using a variety of techniques, including laser drilling, electrochemical machining, electrical-discharge machining, and water jet drilling. The film-cooling holes 14 are typically fairly small in diameter ranging from about 0.25 mm to about 1.8 mm in diameter. Typically, smaller diameters are used for aircraft applications, and larger diameters are used for stationary power applications. The length of the film-cooling holes 14 depends on the thickness of the wall 12. Typically, wall thickness is in a range of about 0.6 mm to about 2.5 mm for aircraft applications and in a range of about 1.3 mm to about 5 mm for stationary power generation applications.

[0032] Film-cooling holes 14 have a number of geometries, the most common being round or shaped holes. The present invention is not limited to any specific film-cooling hole geometry and encompasses, for example, round and shaped holes. Both round holes and shaped holes are known. Shaped holes are discussed, for example, in commonly assigned U.S. Patent Number 6,368,060, Fehrenbach et al, entitled "Shaped Cooling Hole for an Airfoil," which is hereby incorporated by reference in its entirety.

[0033] The flow modifier 30 is described in greater detail with reference to Figures 3-7 and 17. For the embodiment illustrated in Figure 3, the flow modifier 30 is situated on the hot surface 22 of wall 12 and does not extend over the exit site 16. The flow modifier 30 may be formed in a variety of shapes. Exemplary flow modifier shapes are shown in Figures 4-7 and include a rounded flow modifier (Figure 6). Triangular flow modifiers 30 are illustrated in Figures 4 and 7, and a trapezoidal flow

modifier is shown in Figure 5 (collectively "polygonal flow modifiers"). The rounded flow modifiers 30 may be circular (as shown) or elliptical in cross-section. Further, although the flow modifiers 30 are shown as regular shapes (circles, triangles etc) for simplicity, the flow modifiers 30 may also be irregularly shaped.

[0034] As illustrated in Figures 6 and 7, for example, a number of flow modifiers 30 may be associated with each of the exit sites 16. In other words, for certain embodiments, there are a number of flow modifiers 30 for each film-cooling hole 14.

[0035] Figure 17 shows another exemplary flow modifier 30 embodiment. As shown, a v-shaped flow modifier 30 is positioned upstream of the exit site 16 of the film-cooling hole 14 to divert the hot gases around the exit site 16.

[0036] The flow modifiers 30 are positioned relative to the exit site 16 in order to enhance the flow of coolant from film-cooling hole 14 and through exit site 16 toward the hot surface 22 of the component wall 12. Other criteria for positioning the flow modifiers 30 include directly blocking the flow of hot gases toward the hot surface 22 of the wall 12. For the embodiments of Figures 4-6, the flow modifiers 30 are positioned on the downstream side 24 of the exit site 16. For the embodiment illustrated in Figure 7, the flow modifiers 30 are positioned on the lateral sides 26 of the exit site 16. Flow modifiers 30 may be arranged on both the downstream and lateral sides 24, 26 of the exit site. (For brevity, this arrangement is not illustrated.) In addition, the flow modifiers 30 may be positioned on the upstream side 25 of the exit site 16.

[0037] As discussed above, a number of film-cooling holes 14 may be desirable to achieve the desired level of cooling. Accordingly, for a specific embodiment, the component 10 includes a number of film-cooling holes 14 extending through the wall 12 for flowing a coolant from the cold surface 21 to the hot surface 22 of the wall 12. Each of the film-cooling holes defines a respective exit site 16 in the hot surface 22 of the wall 12. As indicated in Figure 1, for example, the film-

cooling holes 14 are arranged in at least one row 32. A number of flow modifiers 30 are formed on the hot surface 22 of the wall. As indicated in Figure 1, at least one of the flow modifiers 30 is associated with a respective one of the film-cooling holes 14 and is adapted to direct the coolant flowing from the respective film-cooling hole 14 and out of the respective exit site 16 toward the hot surface 22 of the wall 12. For the embodiment illustrated in Figure 1, the film-cooling holes 14 are arranged in a number of rows 32. At least a subset 34 of the flow modifiers 30 are situated between the rows 32 of film-cooling holes 14. The flow modifiers 30 situated between the rows 32 are adapted to enhance the flow of coolant along the hot surface 22 between the rows 32.

[0038] A more particular embodiment is illustrated in Figures 8 and 9. Figure 8 shows an exemplary arrangement of film-cooling holes, flow modifiers and connectors for a hot gas path component. Figure 9 is a view of the flows modifiers and connectors of Figure 8 taken along the line 43. For this embodiment, the component 10 includes a number of film-cooling holes 14. As shown, a number of connectors 18 are formed on the hot surface 22 of the wall 12. Each of the connectors extends outwards from the hot surface 22 of the wall 12 and conforms to the hot surface 22 of the wall 12, as indicated in Figure 9. The connectors 18 are adapted to enhance interaction between each of a number of coolant flow streams associated with the respective film-cooling holes 14.

[0039] Figure 10 shows the hot surface 22 of the component wall 12, with two exemplary ridges 38 formed on the hot surface 22. As shown, the ridges extend along at least a portion of the exit site 16 and further extend to a position downstream of the exit site 16. The ridges 38 may be rounded or angled and may have constant or varying dimensions. The ridges 38 may be used in conjunction with flow modifiers 30, as shown in Figure 10. Alternatively, the component 10 may include either ridges 38 or flow modifiers 30. According to a more particular embodiment, the ridges 38 extend outwards from the hot surface 22 of the wall 12 and conform to the hot surface 22, as indicated for example in Figure 11. For certain embodiments, the component

10 includes a number of ridges 38, where at least two ridges 38 extend along at least a portion of the exit site 16 of a respective film-cooling hole 16 and further extend downstream of the respective exit site 16, as shown for example in Figure 10.

[0040] As discussed above with respect to the flow modifier 30 embodiments, the component 10 typically includes a number of film-cooling holes 14. For particular embodiments, the film-cooling holes are arranged in several rows 32, including a first and a second row 32, as shown for example in Figure 12. A number of ridges 38 are formed on the hot surface 22 of the component wall 12. For the arrangement of Figure 12, the ridges 38 extend along at least a portion of the exit sites 16 in the first row 32 and further extend downstream of the exit sites 16 in the second row 32.

[0041] For the embodiments discussed above, the flow modifiers 30 are formed on the component wall. Another flow modifier 30 embodiment is illustrated in Figures 13 and 14. As shown in Figure 14, the flow modifier 30 is formed on the passage wall 36 and is adapted to spread the coolant flowing from the film-cooling hole 14 and out of the exit site 16 laterally. For the particular embodiment shown in Figure 14, the flow modifier 30 is coextensive with the hot surface 22 of the component wall 12. For another embodiments (not shown in side view), the flow modifier 30 extends out of the exit site 16 and above the hot surface 22 of the component wall 12. For another embodiment (also not shown in side view), the flow modifier 30 is contained within film-cooling hole 14 and does not reach the hot surface 22 of the wall 12. The flow modifiers 30 formed within film-cooling hole 14 may have the various shapes discussed above. For example, the flow modifier 30 may be rounded, including circular or elliptical shapes. The flow modifier 30 may also be polygonal, for example triangular or trapezoidal. The flow modifier 30 may also be irregularly shaped, including a combination of rounded and angular features. In addition, a number of flow modifiers 30 may be formed within each exit site 16. For the particular embodiment of Figure 14, the flow modifier 30 is positioned on a downstream side 24 of the exit site 16. Further, as discussed above, the film-cooling

holes 14 are not limited to a specific geometry. For example, the flow modifier 30 may be formed in both round holes and shaped holes.

[0042] A turbine assembly 100 embodiment is described with reference to Figure 15. As indicated, the turbine assembly 100 includes a first component 110 and a second component 112. The first and second components 110, 112 define a secondary cooling slot 114. The secondary cooling slot 114 receives and guides a secondary coolant flow. Exemplary components 110, 112 that define a secondary cooling slot 114 include: a combustor and a turbine inlet nozzle, a combustor and a nozzle (stationary vane), a nozzle and a blade, a nozzle and a shroud, a blade and a shroud, two nozzles, and two blades. The turbine assembly further includes at least one flow modifier 30 formed on a surface of one of the first and second components 110, 112. For example, if the component is a blade, the flow modifier may be formed on the platform. If the component is a nozzle, the flow modifier may be formed on an end wall. If the component is a shroud, the flow modifier 30 may be formed on the shroud. The flow modifier 30 is adapted to enhance the secondary coolant flow along at least one of the first and second components 110, 112 within the secondary coolant slot 114. In this manner, the flow modifier 30 enhances the cooling of the components 110, 112 by the secondary coolant flow.

[0043] Two exemplary flow modifier 30 configurations are shown in Figure 15. The exemplary flow modifier 30 shown on the first component 110 extends partially along the slot 114, whereas the exemplary flow modifier 30 shown on the second component 112 extends along the slot 114 and onto the hot gas path surface 116 of the second component 112. Beneficially, extending the flow modifier 30 onto the hot gas path surface 116 transitions the coolant flow to further enhance protection of the surface 116 by reducing mixing of the coolant with the hot gases. Figures 18 and 19 show exemplary arrangements of flow modifiers 30 on the sides 118 of the components 110, 112 that face the slot 114. More particularly, Figure 18 illustrates an arrangement of linear flow modifiers 30 configured to act as radial surface guides for the coolant. Figure 19 illustrates an arrangement of arcuate flow modifiers 30 also

configured to act as radial surface guides for the coolant. Beneficially, the curved flow modifiers of Figure 19 impart swirl to the coolant flow exiting the slot 114 to better match the hot gas flow, thereby reducing mixing losses.

[0044] For the embodiment shown in Figure 15, the flow modifier 30 extends into secondary cooling slot 114. The flow modifier 30 is described above. According to a particular embodiment (not expressly shown), the flow modifier 30 forms a ridge 38 extending along one of the components 110, 112.

[0045] A method embodiment for forming a flow director 20 on a component 10 comprising a wall 12 is described with reference to Figure 16. As noted above, exemplary components 10 include hot gas components 10 for turbine assemblies 100. The method includes depositing at least one layer 40 on the wall of the component 10. The deposition includes shaping the layer 40 in accordance with a predetermined shape to form the flow director 20. The predetermined shape can be any desired shape. Because the flow director is formed by depositing one or more layers 40 on the wall 12, the flow director 20 conforms to the wall 12 of the component 10. For a particular embodiment, the deposition comprises depositing a number of layers 40 on the wall 12 of the component 10 and shaping the layers 40 in accordance with the predetermined shape to form the flow director 20. It should be understood that "the predetermined shape" refers to the overall shape of the flow director 20 and that the respective layers 40 may have different dimensions. Although only shown from a side view, the flow director 20 is three-dimensional, and exemplary flow directors 20 include connectors 18, flow modifiers 30, and ridges 38, which are described above.

[0046] The layers 40 may be formed from a number of materials, and exemplary layers 40 are formed of metal, ceramic or combinations thereof. For example, one or more metal layers may be deposited on a metallic or ceramic component 10. Similarly, one or more ceramic layers 40 may be deposited on a metallic or ceramic component 10. Exemplary ceramics include ceramic matrix composites and monolithic ceramics. Moreover, the layer 40 and component 10 materials need not coincide. For example, one or more ceramic layers 40 may be

deposited on a metal component 10. The layers 40 may also form a graded material, for example a ceramic layer 40 formed on a metallic layer 40. In addition, the layers 40 may be formed on a coating on the wall 12. This latter configuration is also intended to be encompassed by the phrase "depositing on the wall 12." In addition, other coatings may be deposited on the wall 12 over the one or more layers 40, for example thermal barrier coatings (not shown).

[0047] For the embodiments of Figures 3 and 11, the wall 12 has a cold surface 21 and a hot surface 22, and the film-cooling hole 14 extends through the wall 12 for flowing a coolant from the cold surface 21 to the hot surface 22. The film-cooling hole 14 defines an exit site 16 in the hot surface 22 of the wall 12. For this embodiment, the deposition comprises depositing one or more layers 40 on the hot surface 22 of the wall. For the particular embodiment of Figure 3, the flow director 20 takes the form of a flow modifier 30 adapted to direct the coolant flowing from the film-cooling hole 14 and out of the exit site 16 toward the hot surface 22 of the wall 12. The one or more layers 40 may be shaped in a number of geometries to form a flow modifier 30 having any of the geometries discussed above with respect to Figures 4-7, for example.

[0048] For the embodiment of Figures 11 and 12, the flow director 20 takes the form of a ridge 38 extending along at least a portion of the exit site 16 and further extending to a position downstream of the exit site 16. The one or more layers 40 may be shaped to form a rounded or angled ridge 38 and to form a ridge with constant or varied dimensions (for example, width and depth).

[0049] An exemplary deposition process is described with reference to Figure 16. As indicated, the deposition process includes delivering a mixture 50 through a nozzle 52 (sometimes called a "pen" 52) onto the wall 12 to form the layer 40. The mixture 50 comprises a powder 54 dispersed in a liquid medium 53. This deposition process is commonly called the "direct write" process. "Direct write" processes encompass numerous ways to deposit layers on components. One example of a "direct write" process is the "pen-type." More particularly, for a pen-type deposition

system, the mixture 50 is forced through the nozzle 52 at a controlled rate, to achieve a desired layer 40 geometry. As used here, the term "geometry" encompasses shape and dimensions. An exemplary dimension is thickness. The size of the nozzle 52 orifice is selected to provide a desired dimension (for example, width) for each pass of the nozzle 52. Exemplary sizes of the nozzle 52 orifice range from about 0.010 mm to about 1.0 mm. During the deposition, the nozzle 52 is displaced relative to the wall 12 to form the layer(s) 40 in accordance with the predetermined shape. By "displaced," it is meant that either the nozzle 52 or the wall 12 is moved or both the nozzle 52 and the wall 12 are moved. Typically, the wall 12 is moved. The predetermined shape may be generated and stored in a computer as a CAD/CAM file. As indicated in Figure 16, the movement of the nozzle 52 relative to the wall 12 may be controlled, for example by a controller 56, to form the layer(s) 40 in accordance with the predetermine shape. An exemplary controller 56 is a computer 56 operating a CAD/CAM program. In this manner, the layer shape and thickness and other parameters are precisely controlled.

[0050] Beneficially, the nozzle 52 can follow along the component wall 12 at a controlled distance therefrom, for example with a separation less than about 25 micrometers. In this manner one or more layers 40 having a substantially uniform thickness may be deposited rapidly and precisely on the component wall 12. Beneficially, the layers 40 may be deposited rapidly and precisely on a complex-shaped component wall 12 in an automated manner.

[0051] As noted above, the powder 54 of the layer material or its precursor is dispersed in a liquid solvent medium 53, such as an alcohol, which can optionally contain a binder, surfactant, or other additives to enhance properties such as adhesion and wetting of the mixture 50 on the wall 12, or a rheology modifier to adjust the viscosity of the mixture 50. Typically, the consistency of the mixture 50 resembles that of toothpaste. The mixture 50 may also include a material that promotes the conversion of a metallic ingredient to a compound thereof or as pore formers in the heat treated structure. The mixture 50 may also include a temporary binder, such as

starch or cellulose, to enhance the integrity of the deposited layer(s) 40 before any subsequent treatment thereof. Formation of the mixture 50 may include mixing the powder 54 and liquid medium 53, as well as any optional surfactant, temporary binder, and any other constituents of the mixture 50 in a conventional mixer (not shown), such as a rotating canister, high-speed blender, ribbon blender, or shear mixer like a roll mill.

[0052] To remove the liquid medium 53 and to consolidate the layer(s) 40, a particular embodiment of the method further includes heating the layer 40 by itself or with the component to a predetermined temperature. Exemplary heat treatments include focused energy sources such as plasma, laser or electron beam heating or another local heat source. Alternatively, the heat treatment may comprise heating the component 10 in a furnace (not shown), provided the sintering temperature of the layer(s) 40 is below the softening point of the component 10.

[0053] In order to form a number of flow directors 20 on the component wall 12, the deposition is repeated a number of times at a number of positions on the component wall 12, according to a more particular embodiment.

[0054] The method may also be employed to form one or more flow directors 20 for the turbine assembly embodiment of Figure 15.

[0055] Other exemplary deposition processes include chemical vapor deposition, ion plasma deposition, electron beam physical vapor deposition, and electroplating. These deposition processes may include one or more masking steps.

[0056] Although only certain features of the invention have been illustrated and described herein, many modifications and changes will occur to those skilled in the art. It is, therefore, to be understood that the appended claims are intended to cover all such modifications and changes as fall within the true spirit of the invention.